



# Valorisation and Dissemination of Secondary Metallurgy Technology

## **DissTec**

Contribution to define a  
Road Map  
For Secondary Steelmaking Operations

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Scope of the presentation: Future scenario for secondary steelmaking technology

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- Integration of models and measurements

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- Intelligent manufacturing

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# Scope of the presentation



In the frame of research projects on secondary metallurgy technology a big effort has been addressed to the development of measurements, analysis and models for improving steel quality.

As a consequence of this effort, today the secondary steelmaking operations can be accurately designed off-line.

A step forward would be the availability of reliable and powerful techniques for collecting and elaborating information on-line and real time control of the operations in ladle.

This possibility would increase a lot the ability to produce high quality steel reducing operational time and cost, with a consequent positive impact on competitiveness.

The presentation shows examples of developments in this direction.

# Emerging trends



Some emerging trends are already clear.

- Stronger integration of models with new and continuous measurements for process **optimization and control**
- Improving and applying mathematical algorithms and methods for the **Multi Objective Optimization** approach
- Implementation of measurements and models allowing decision making for an **Intelligent manufacturing** approach

# Integration of models and measurements



To obtain target quality and process consistency under variable input, integration of new and continuous measurements with accurate process models for **on-line applications** is necessary.

Today sophisticated models allow to perform in a very short time complex calculations taking into account many parameters.

In principle this power could be applied to control each single ladle, in order to precisely obtain target quality.

What is missing is accurate information real time.

# Measurements in ladle - Today



The composition of steel and slag during secondary metallurgy operations in ladle are very crucial factors for reaching the desired final steel quality, in terms of dissolved elements and non-metallic inclusions.

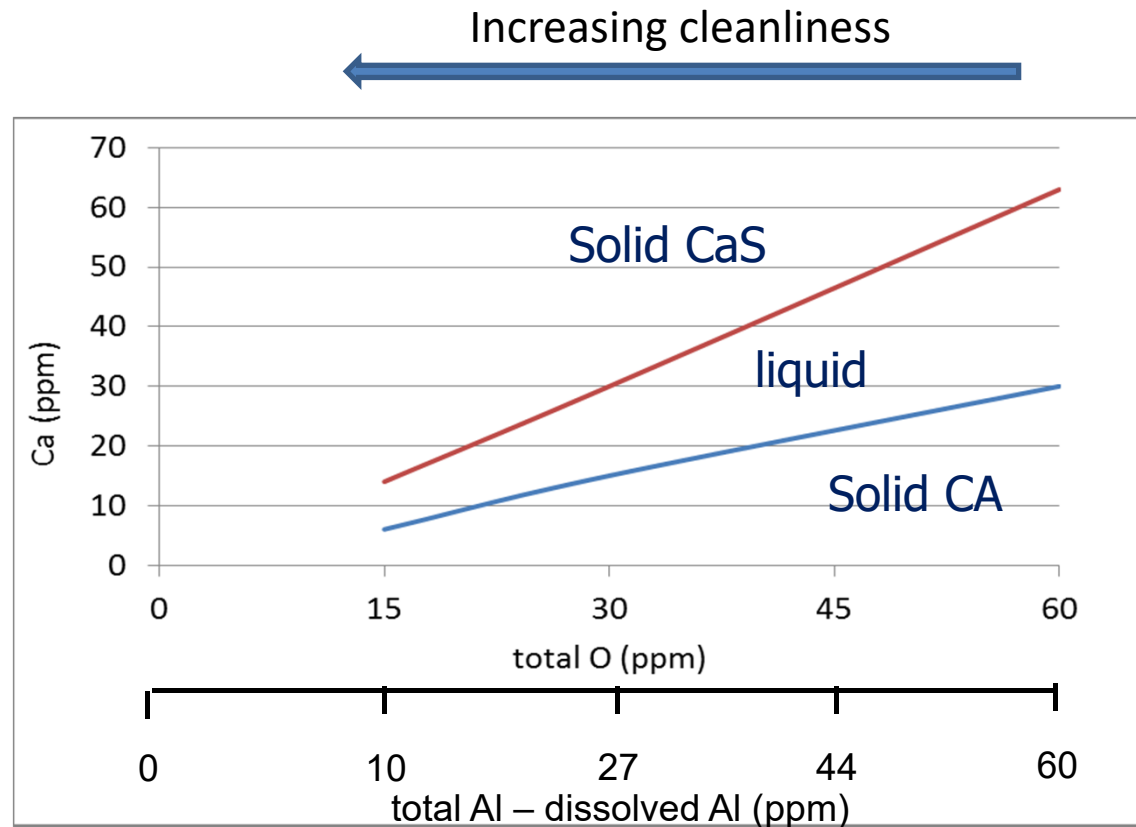
In routine industrial operations steel and slag samples are regularly taken for accurate chemical analysis based on atomic absorption spectrometry, inductively coupled plasma-optical emission spectrometry and x-rays diffraction.

Disadvantages of these techniques are their limit to laboratory use and the necessary sample preparation, which prevent the use for on-line, real time, control.

# Measurements in ladle – Usefulness for models



Calculation of Ca addition from measurements of Al concentration potentially available on-line



Steel: Si 0.45%; Mn 1.5%; Al 300 ppm; S 100 ppm;  
Temp 1600 °C

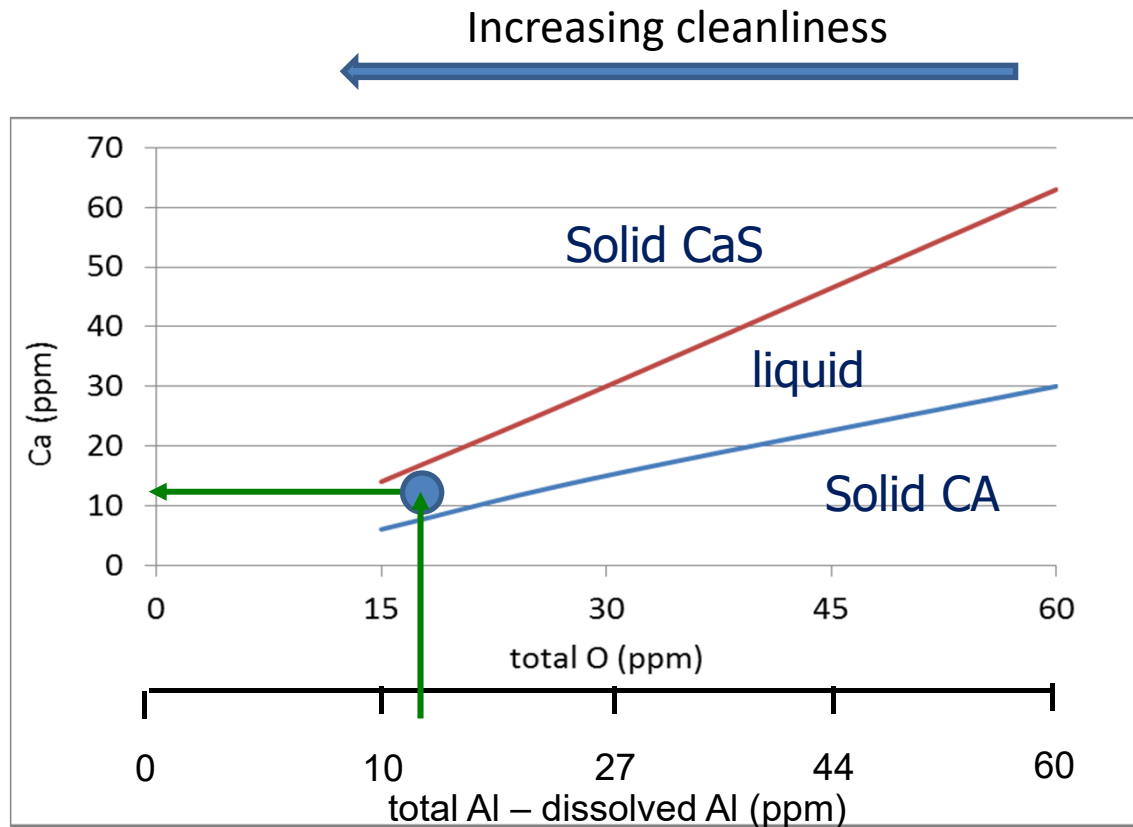
This diagram indicates the windows available for a proper transformation of alumina inclusions into fully liquid aluminates without CaS precipitation in liquid steel. The calculation has been performed starting from concentrations of total and dissolved Aluminum.

It is evident that for low concentration of oxygen the window is narrow, a strict control of Ca addition is necessary.

# Measurements in ladle - Needs



Calculation of Ca addition from measurements of Al concentration potentially available on-line



A precise control of the correct amount of calcium to add requires a precise determination of concentration of total and soluble aluminum.

Today this can be done only with time expensive laboratory analysis.

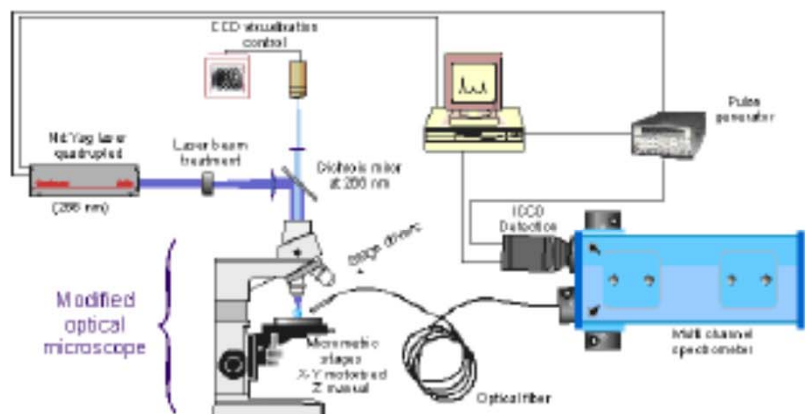
**On-line measurements would open a real time control.**

Steel: Si 0.45%; Mn 1.5%; Al 300 ppm; S 100 ppm;  
Temp 1600 °C

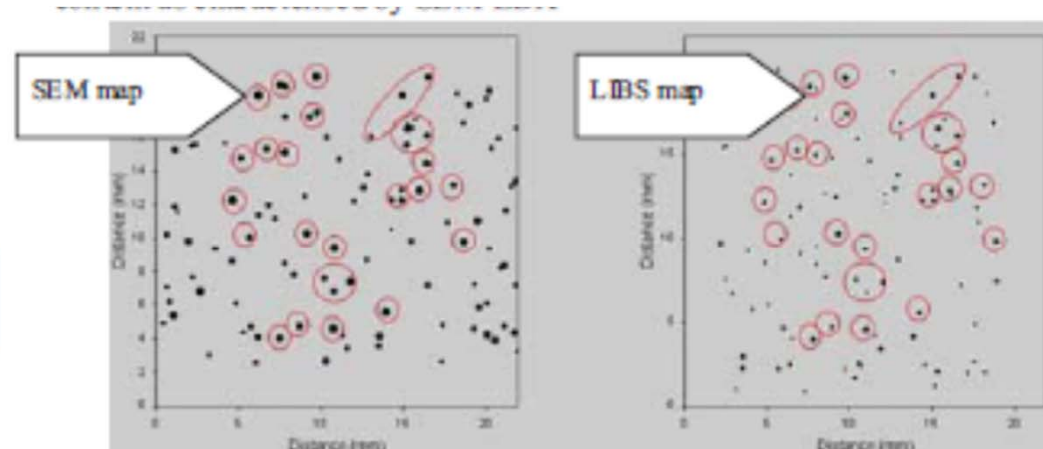


# Measurements in ladle – Possible developments

LIBS (Laser-Induced-Breakdown-Spectroscopy) techniques have been also developed for rapid determination of inclusion population [1], based on the measurements of metals in metallic solution and in oxides.



Schematic of a microprobe LIBS system for rapid inclusion analysis



Comparison of SEM and LIBS maps of inclusions

The development of techniques for determination of species in metals and in oxides in a quick time and accurate way would allow the use of the already existing mathematical model directly on-line.

[1] Development of inclusion reference materials and simultaneous determination of metals and non-metallic inclusions by rapid LIBS analysis in steel samples – EUR 24190 2010

# Measurements in ladle



Important objectives of RFCS research have always been to increase the number and quality of data characterizing steel and slag and their availability in short time during the process, empowering the classical routine measurements, such as temperature, dissolved oxygen concentration, steel and slag composition from samples.

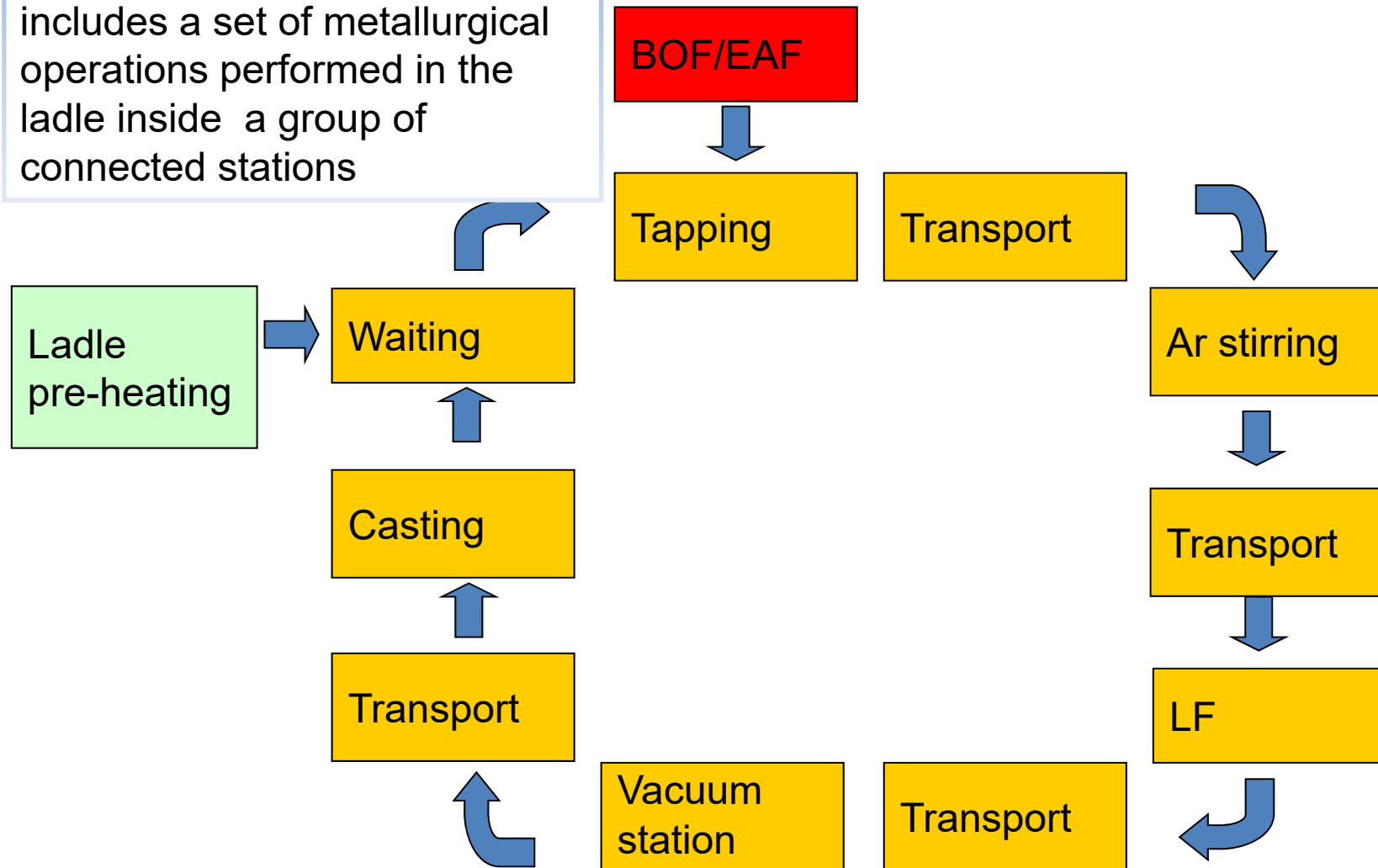
Activities carried out mainly regarded:

- 1) The development of new techniques for more complete and more rapid analysis of chemical composition of steel and slag
- 2) The improvement of sampling and analytical technique for more accurate inclusion analysis

# Multi-objectives approach



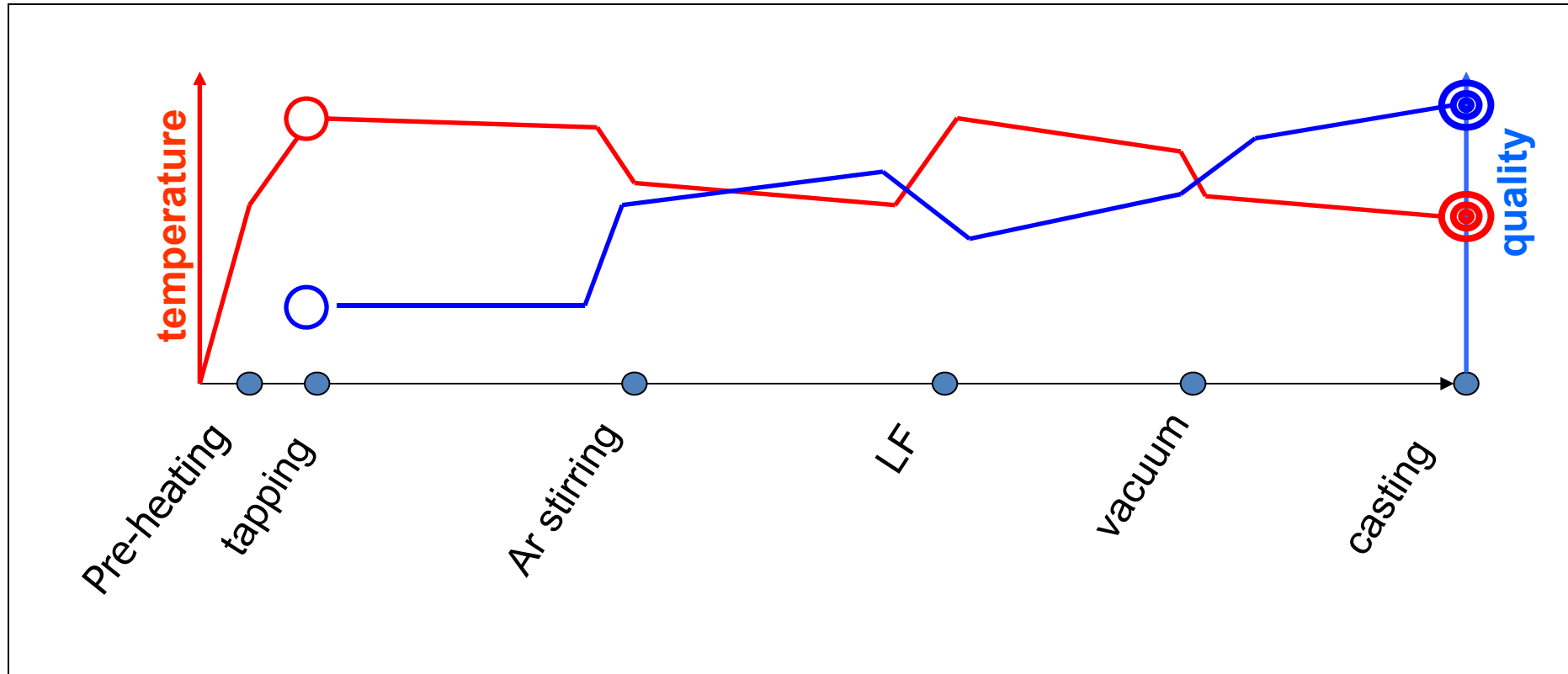
The steel refining cycle includes a set of metallurgical operations performed in the ladle inside a group of connected stations



# Multi-objectives approach



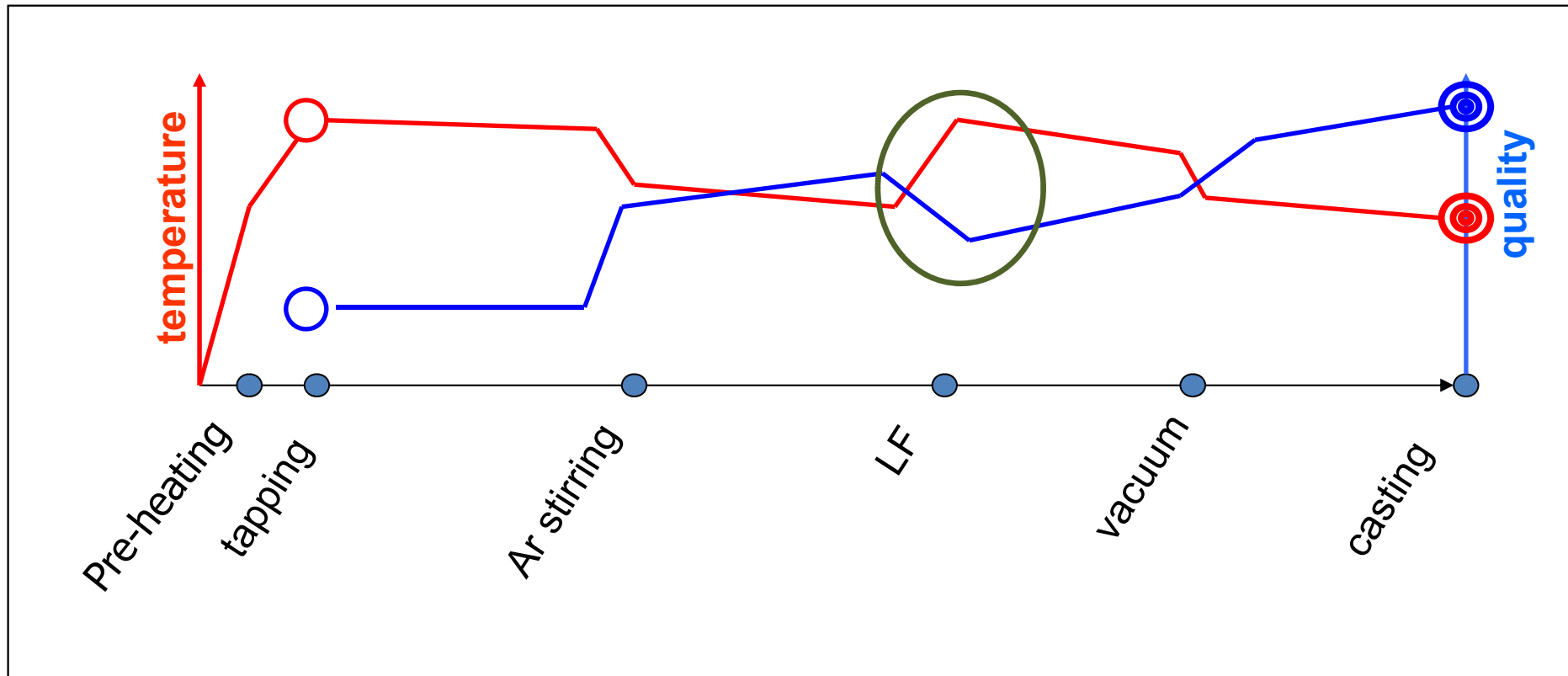
The aim of the cycle is to obtain the target values of steel “quality” and temperature



# Multi-objectives approach



Usually the operating practice are designed in order to optimize the single step (ignoring previous steps and neglecting the effect on the next steps)



# Multi-objectives approach



The large number and the quality of the European researches on secondary steelmaking technology made available a huge knowledge and validated a lot of mathematical models of all the secondary steelmaking operations:

- De-oxidation
- De-sulfurization
- De-gassing
- Ca-treatment
- Inclusion floatation
- Control of re-oxidation problem

# Multi-objectives approach



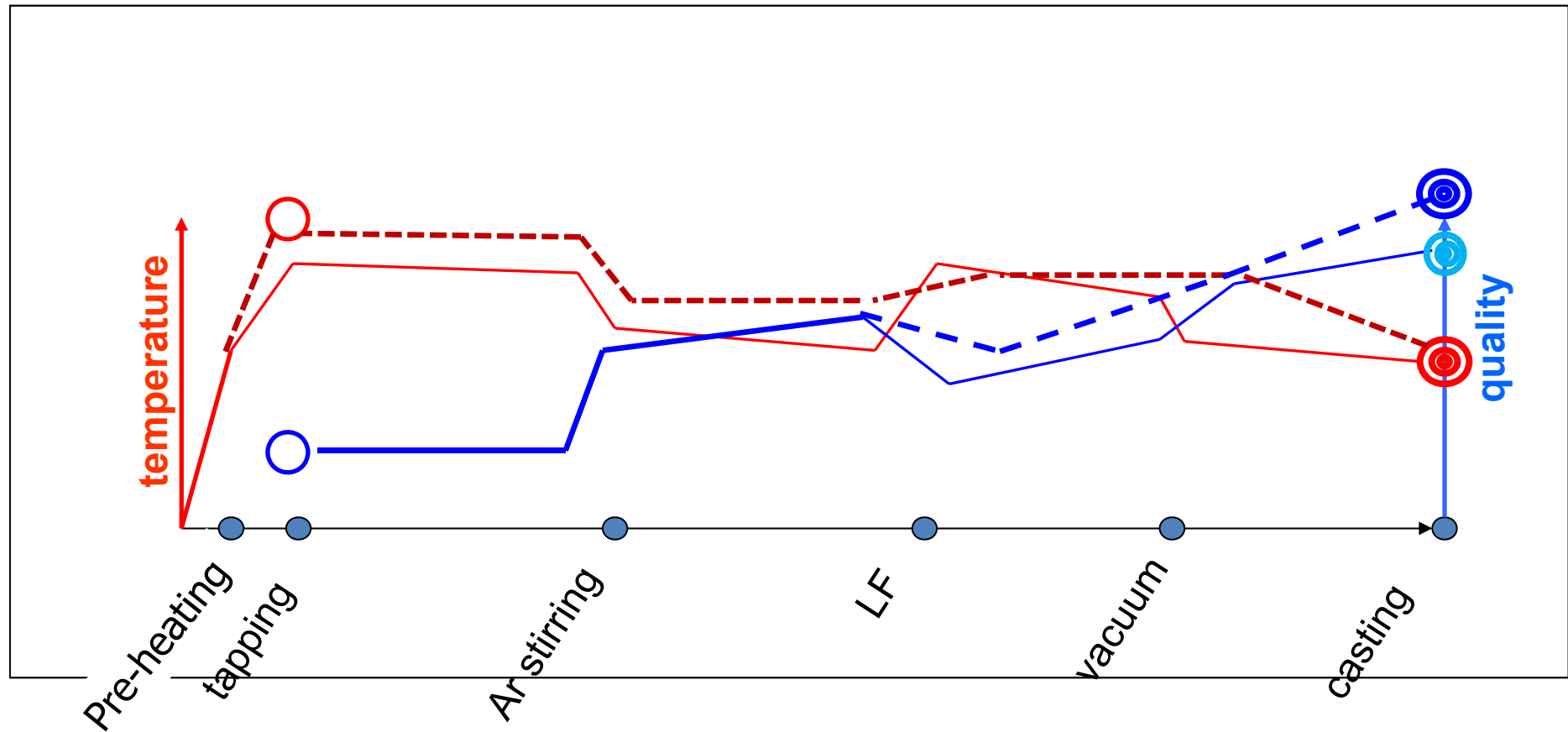
The next challenge is to apply Intelligent Manufacturing practices, considering the whole production cycle, in order to:

- Perform a process step knowing its influence on the following steps
- Choose step procedures that optimises the cycle
- Decide to re-address the cycle or to re-adjust step procedures, when a process parameter exceeds the limiting value

# Multi-objectives approach

A global vision and global optimization can improve the final quality and reduce energy consumption

## Holistic approach



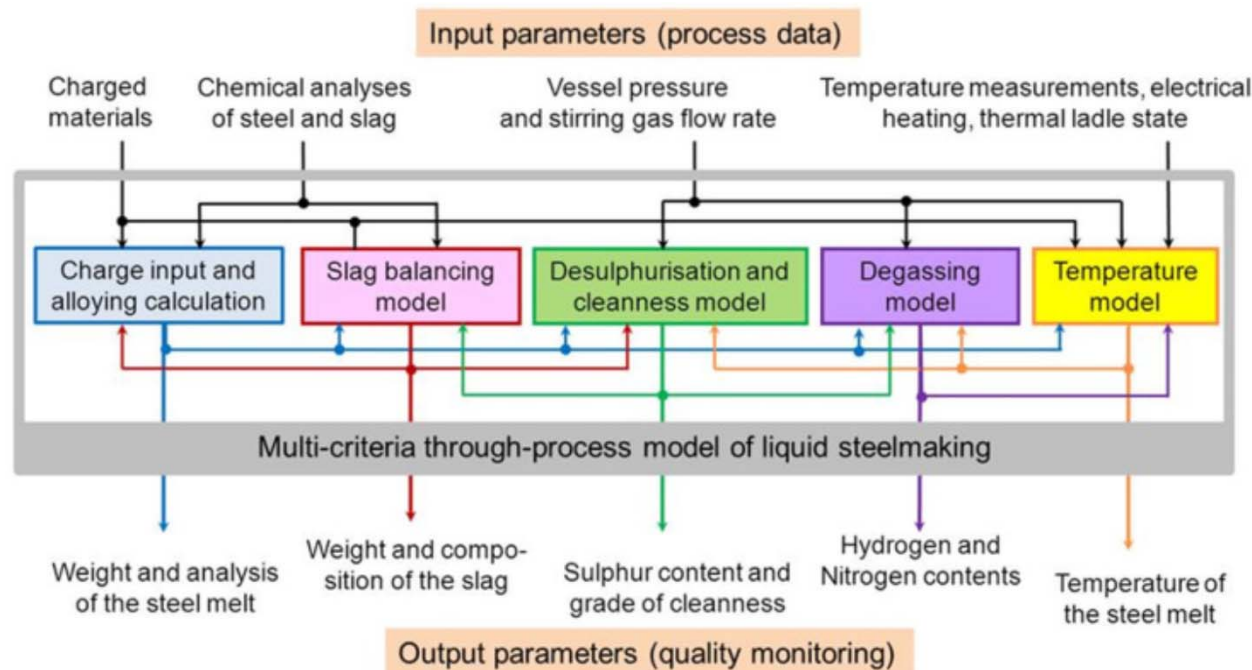


# Multi-objectives approach



Examples of this new trend can be already found in European Project.

The integrated approach has been investigated and exploited in the TotOptLiS [2] Project., where all the refining operations are taken into account by a supervisor system to suggest the appropriate operating instructions of operating conditions and treatment times at each unit in order to arrive on time at the continuous casting machine according to the steel grade requirements.



This integrated approach takes into account the plant constraints and the suggested actions are based on the process knowledge coupled with multi-objective optimization techniques aimed at minimizing energy and costs as well as the production losses in favor of process continuity

[2] TotOptLiS; RFSR-CT-2010-00003;

Multi-criteria through-process optimisation of liquid steelmaking

# Intelligent manufacturing – From inclusion to defects



Inclusions formed during steelmaking operations in ladle and tundish and during solidification are transformed in defects after rolling operations.

The prediction of occurrence, size and harmfulness of defects, using information from the ladle and tundish is difficult, also because fatal defects can be caused by rare large inclusions, not easy to detect.

The ability to get information during steelmaking operations, and before rolling, on the probability to generate defects would give an added value to the inclusion analysis from steel samples, giving the opportunity to rate the quality of a particular heat and to make decisions consequently.

# Intelligent manufacturing



The idea of “Integrated Intelligent Manufacturing” (I<sup>2</sup>M) has been defined by an ESTEP (European Steel Technology Platform) Working Group with the same name.

Where conventional techniques are mature and robust enough to guarantee stable performance, intelligent manufacturing technology should contribute to developing more flexible production processes.

The “Intelligent Manufacturing” is considered an important way to maintain industrial leaderships and sustainability.

Mandatory requirements are:

- process control
- flexibility and quality

By means of measurements and models

# Intelligent manufacturing – an example on inclusions and defects



The idea of the INCLUSION project [3] was to develop a method allowing foreseeing - in a relatively quick and cheap way - the probability of occurrence of not acceptable defects produced in given rolling operations directly from analysis on liquid steel (or at least in as cast products).

On the basis of this information the steelmaker can decide a different rolling procedure, changing the final destination of the product, in order to reduce the probability of downgrading the product.

**The project was in line with the strategic development of intelligent manufacturing techniques**

[3] Innovative methodology for through process inclusion level forecasting of engineering steel (INCLUSIONS)- EUR 26175 -2013

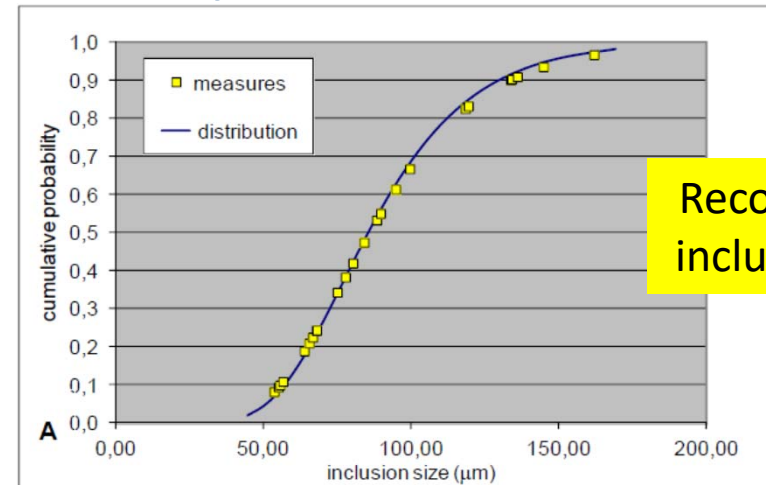


## Extreme Values Analysis (EVA) – A statistical technique of rare events

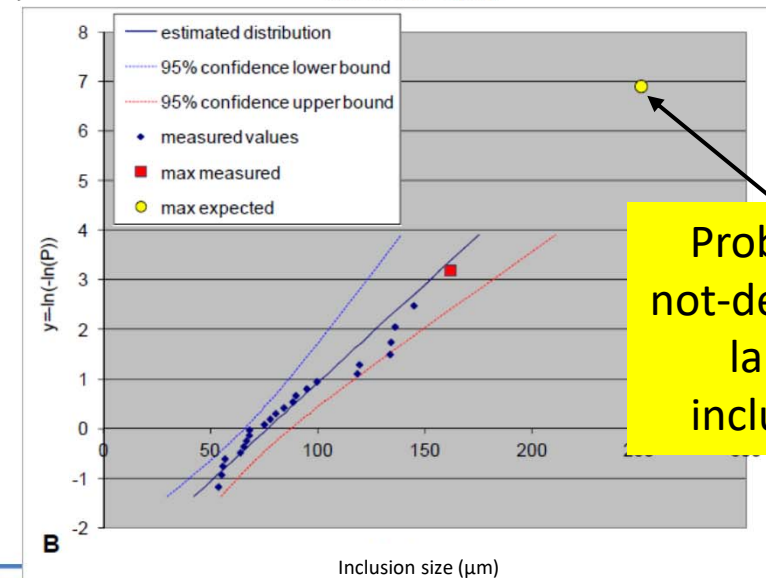
Despite the huge and successful effort performed to improve steel cleanliness, large inclusions – causing defect on the product – can be still present at the end of the secondary steelmaking cycle.

The rarity of these events make difficult their individuation and actuation of countermeasures.

EVA is a statistical techniques able to determine the probability of not-detected large inclusions from analysis of recorded inclusions (in lollipop or in as cast product samples)



Recorded inclusions



Probable not-detected large inclusion

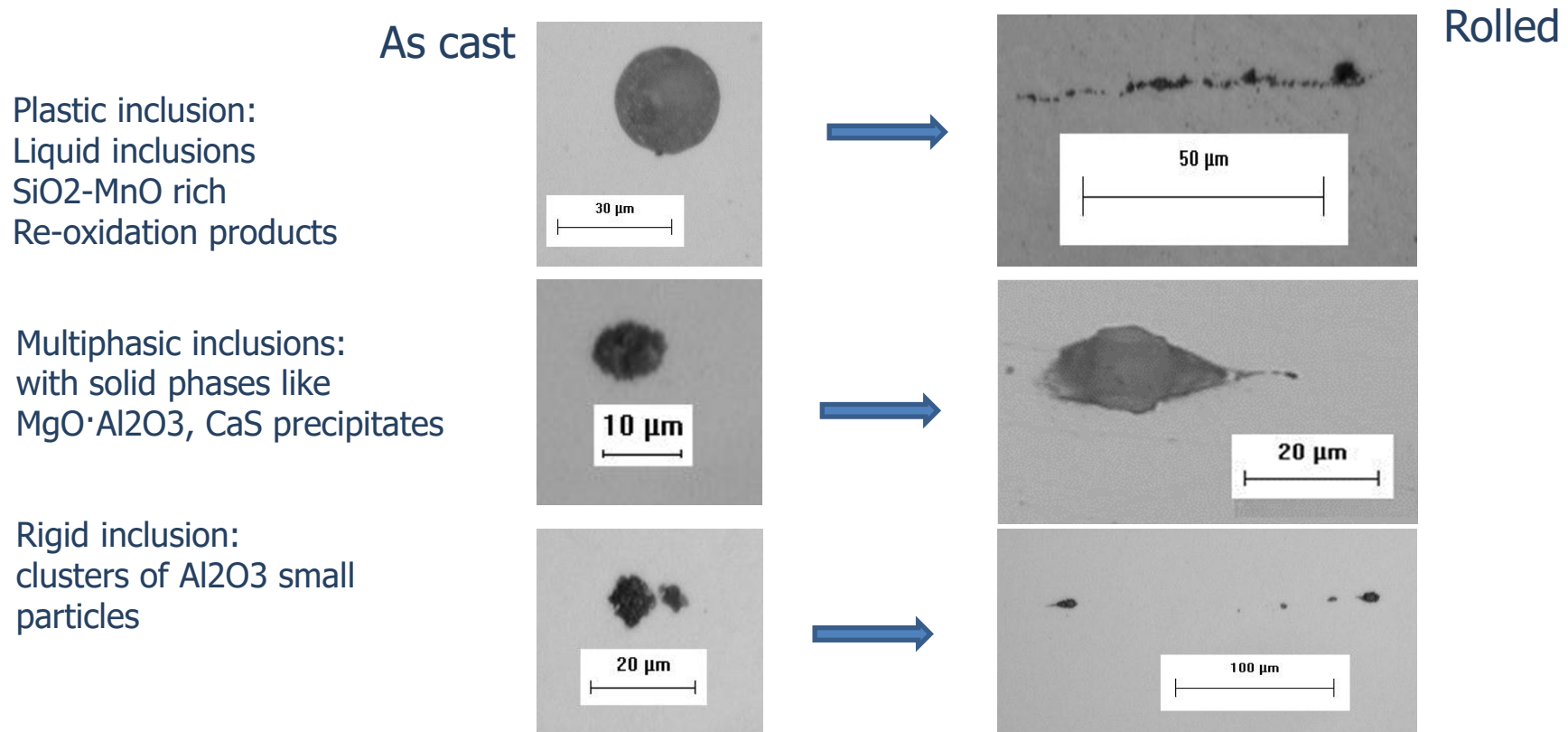
# Intelligent manufacturing – Models for rapid decision making



## Evolution of inclusions in defects

During rolling inclusions present in the final liquid and as cast products, are transformed in defects.

Different types of inclusions generate different defects (which are classified in the standard methods for defects classification and evaluation).





# Intelligent manufacturing – Models for rapid decision making



## Model of inclusion transformation during rolling

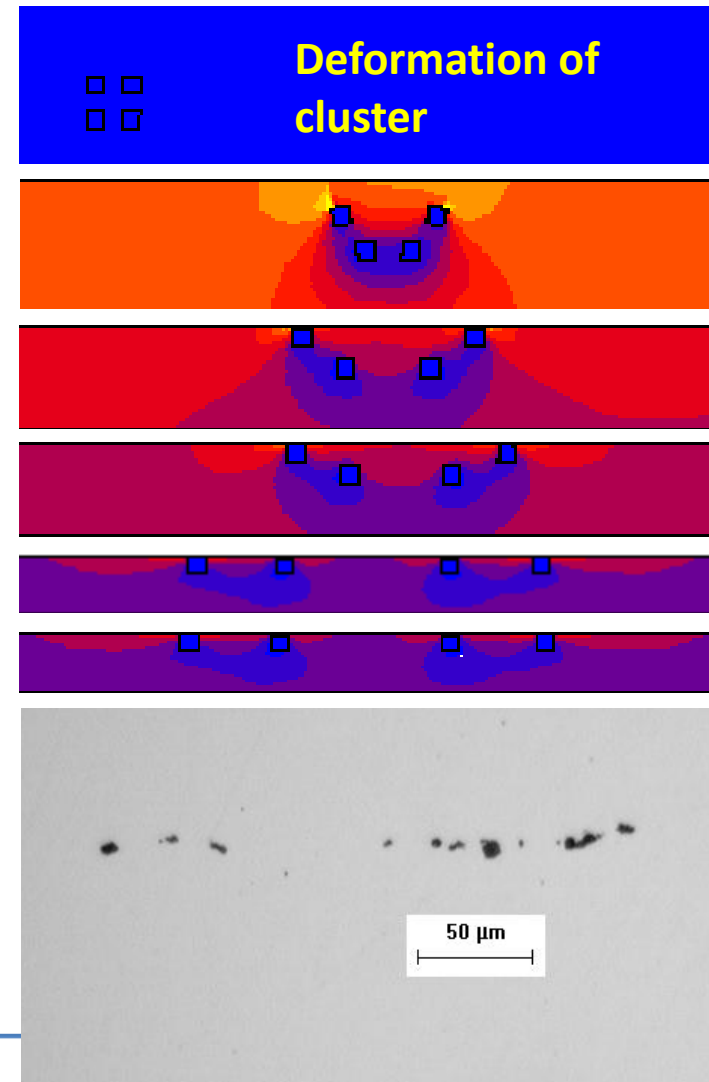
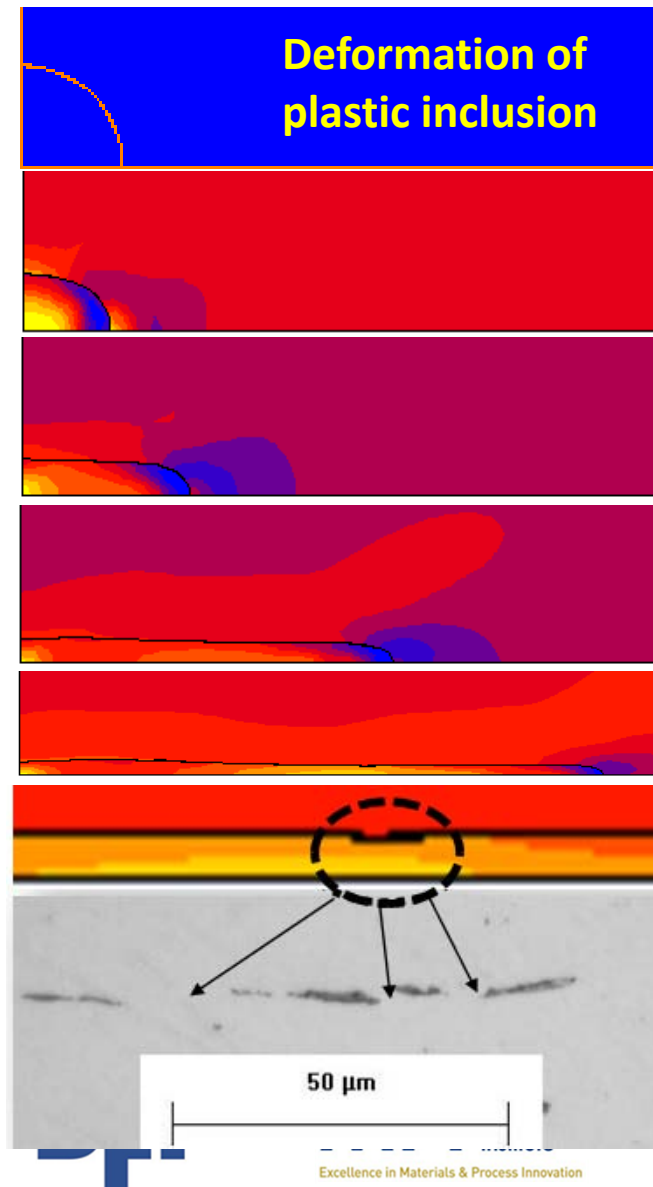
A mathematical model of the model of the deformation of the inclusion during the rolling of the steel product has been developed, based on the rheological properties of steel and inclusion and rolling conditions.

The model predicts the size of the final defects from the characteristics of the original inclusion

# Intelligent manufacturing – Models for rapid decision making



## Model of inclusion transformation during rolling



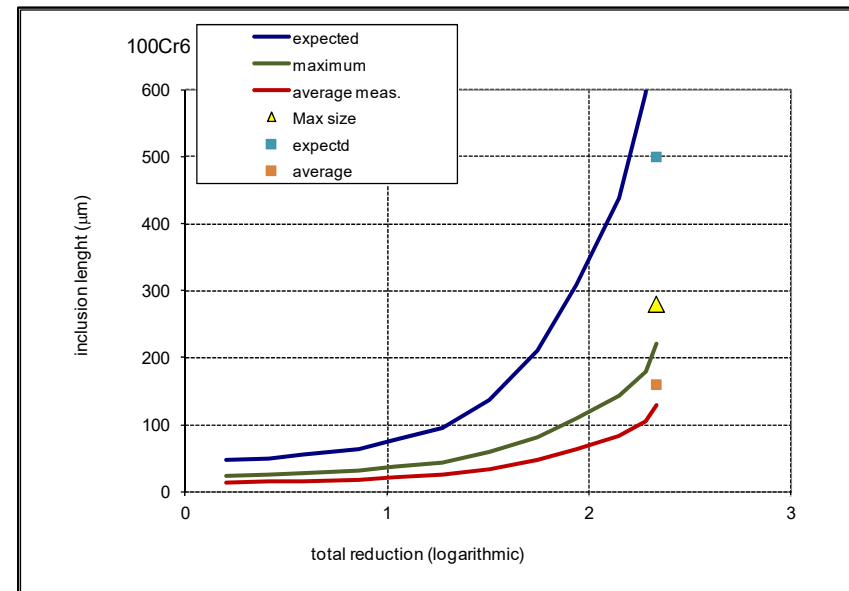
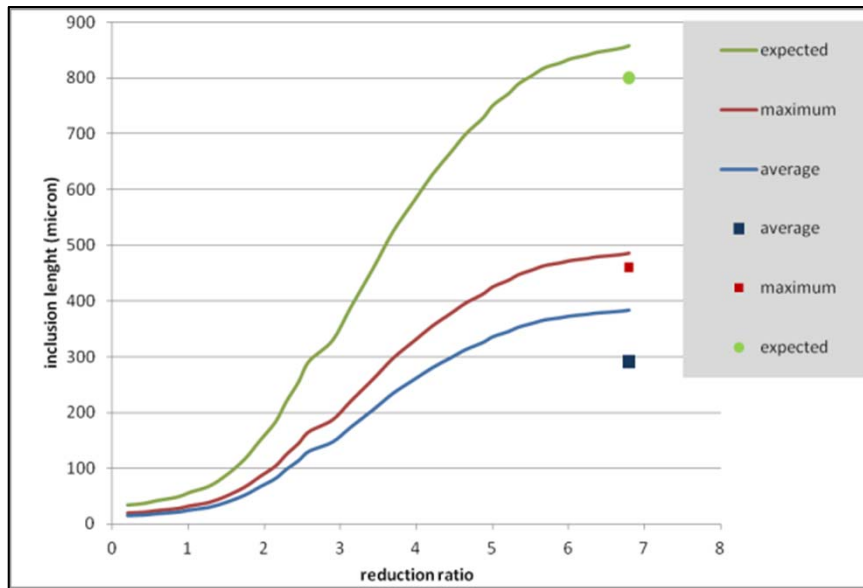
swerea | MEFOS





## Model of inclusion transformation during rolling

The deformation inclusion model has been applied to calculate the defect size expected from probable inclusions estimated with EVA from recorded inclusions, but not actually detected. The predictions of the combination of EVA statistics and inclusion transformation were in agreement with defects found in real products



Comparison between defect size calculated from deformation of inclusion measured and estimated from EVA and defect actually found in products in Cogne (left) and Sidenor (right)

# Intelligent manufacturing – Models for rapid decision making



## Industrial application

The EVA statistics allows to individuate probable big inclusions, causing big defects, using relatively rapid analysis of a single sample.

This information can be exploited real-time for making decision on rolling strategy and product selection, reducing down-grading problems.

The same information can be used to adjust operations in ladle (and tundish) to reduce the occurrence of the problem.

**To make more powerful and useful the technique a rapid and accurate inclusion determination on-line must be developed.**

# Summary and expectations



- ✓ In the European steel industry there is an increase of the production of quality steel, at more and more stringent requirements, and an enlargement of the spectrum of produced steel grades, together with the increase of the variability of raw materials.
- ✓ The consequence is that the control of the operations must be continuously re-tailored, taking into account needs of productivity and product quality, which can vary drastically for different steel grades and from heat to heat, in a flexible way and with an integrated vision. This requires the application of modern and powerful tools to understand complex situation in a rapid way.
- ✓ The large number and the quality of the European researches on secondary steelmaking technology made available a huge knowledge and validated mathematical techniques.
- ✓ A further effort is still necessary to consolidate these achievements in industrial routine applications and to continue the improvement to win the future challenge for the European steel industry.

# Summary and expectations



Some technological trends and research needs are evident. Examples are:

- 1) Development of new on-line measurements allowing the use of the model for real time control
- 2) Stronger integration of the various models in supervisor system for multi-objectives approach
- 3) Application of techniques for making decision in line with the needs of Intelligent Manufacturing



Thank you

